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(71) Applicant *(for all designated States except US)*: RENISHAW PLC [GB/GB]; New Mills, Wotton–under–Edge, Gloucestershire GL12 8JR (GB).

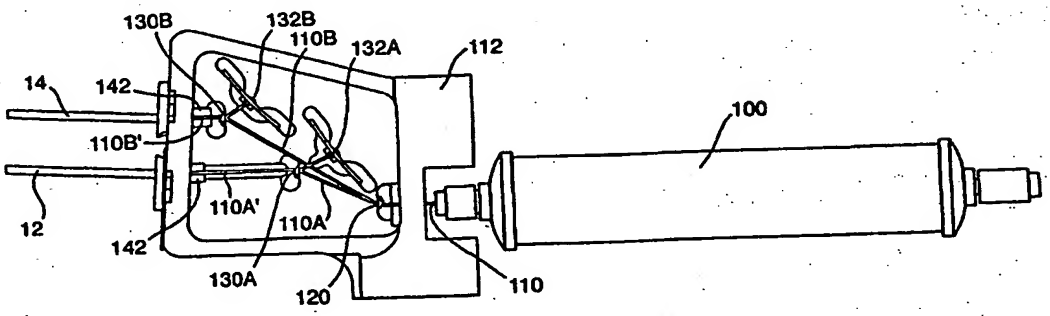
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: CHANEY, Raymond, John [GB/GB]; Laburnum Cottage, New Brookend, Berkeley, Gloucestershire GL13 9SF (GB). CHAPMAN, Mark, Adrian, Vincent [GB/GB]; 116 Bearlands, Wotton–under–Edge, Gloucestershire GL12 7SB (GB). LIAO, Tingdi [CN/GB]; 14 Gloucester Street, Wotton–under–Edge, Gloucestershire GL12 7DN (GB). LINNENBUERGER, Jan [DE/GB]; 26 Woodlands Road, Charfield, Gloucestershire GL12 8LS (GB). NORTHEAST, Damon, Mark [GB/GB]; 18 Durns Road, Wotton–under–Edge, Gloucestershire GL12 7JD (GB).

(74) Agent: WAITE, John; Renishaw plc, Patent Department, New Mills, Wotton–under–Edge, Gloucestershire GL12 8JR (GB).

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(54) Title: APPARATUS FOR PRODUCING AND GUIDING A LIGHT BEAM



(57) Abstract

Apparatus for producing and guiding a light beam, in particular for a laser interferometer, includes a laser having a laser tube (100) and an external cavity (112). Two laser beams (110A' and 110B') of orthogonal polarisation states are directed from the cavity into polarisation maintaining fibres (12, 14). The two beams are generated from a single beam (110) by a birefringent prism (120) in the cavity. Additional beam steering prisms (130A and 130B) are included to direct the beams from the birefringent prism to the fibres. The additional steering prisms compensate for temperature induced beam deviations in the birefringent prisms. Interferometric sensing heads (20, 22) receive the beams from the fibres and include a rotatable wedge prism and mechanical adjustment means for guiding the beams onto reflecting surfaces on an object for positioning the object. The ends of the fibres attached to the sensing heads are kinematically located in the head.

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APPARATUS FOR PRODUCING AND GUIDING A LIGHT BEAM

The present invention relates to apparatus for producing and guiding a light beam, and relates in particular to a laser and to a sensing head which may be used, for example, in a laser interferometer to measure displacement of an object.

The use of laser interferometer apparatus for measuring displacement is well known. Typically, a laser beam is split into two parts, one of which is directed along a fixed reference path, and the other of which is directed towards an object whose displacement is to be measured. Reflected beams from the fixed reference path and the object are recombined to generate an interference beam whose instantaneous intensity varies with displacement of the object being measured. By monitoring a cyclic variation in the intensity of the interference beam, an incremental count corresponding to displacement of the object relative to some reference position, or datum, may be generated.

It is known to employ such apparatus in order to determine the displacement of a stage which is movable in two mutually orthogonal directions, known as an XY stage.

In such apparatus two laser beams are required to enable two laser interferometers to be used to measure displacements of the stage in two orthogonal directions.

In one apparatus, currently marketed by Hewlett-Packard Corporation, it is known to derive the two laser beams

from a single beam output by a laser, by placing one or more beamsplitters in the path of the laser beam to direct different portions of the beam to different parts of the apparatus.

An object of the present invention is to provide a laser which outputs two beams directly.

This object is achieved in accordance with one aspect of the present invention which provides a laser, for generating a laser beam, and a cavity external to the laser which receives, at an input end thereof, the beam from the laser, wherein two fibre optic cables are provided each of which has an end attached to an output face of the cavity, and an optical system is positioned in the cavity to receive the laser beam, said optical system comprising a birefringent prism which produces from the laser beam two beam parts which are directed into said ends of the fibre optic cables.

One problem associated with such a laser is that the angle of deviation of a laser beam passing through the optical components can vary with changes in temperature.

According to a novel aspect of the invention, the optical system in the cavity comprises two further beam steering prisms which direct the beam parts from the birefringent prism onto the ends of the fibre optic cables.

By this means any deviations in the angles of the beam parts produced by the birefringent prism which are caused by temperature variations in the laser cavity,

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can be removed by the beam steering prisms which are subjected to the same temperature variations. It is preferable that the three prisms are identical.

The laser is preferably a gas laser which includes a thermally controlled laser tube to which the cavity is attached.

In a preferred embodiment of the invention, the laser tube produces a laser beam which has two orthogonal polarisation states, the birefringent prism splits the laser beam into its two polarisation states and the fibre optic cables which receive the two beam parts are made from polarisation maintaining fibres.

An embodiment of the present invention will now be described, by way of example, and with reference to the accompanying drawings, in which:

Fig 1 is a perspective view of an interferometric measuring apparatus incorporating a laser and a remote sensing head according to different aspects of the present invention;

Figs 2a and 2b are respectively a perspective view and a plan view of the laser of Fig 1;

Fig 3 is a perspective view of a remote sensing head of Fig 1 showing the optical components inside;

Fig 4 is a view of the main optical components of the sensing head of Fig 3;

Figs 5a and 5b are respectively a plan and cross-section of the sensing head of Fig 4 showing a detail of the cable attachment; and

Fig 6 shows detail of the beam steering prism of Fig 3.

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Referring now to Fig 1, a laser interferometer measuring apparatus includes a laser head 10 which emits a pair of laser beams which, in this example, have orthogonal polarisation states and different frequencies. The laser beams are directed along polarisation maintaining optical fibres 12,14 to remote sensing heads 20,22 respectively. The remote sensing heads 20,22 effectively measure displacement of an object 50 in mutually orthogonal directions defined by respective pairs of output beams 40,42, which are incident upon plane mirrors 60,62 mounted to the object 50. Each of the sensing heads generates an electrical output from which an incremental count indicative of displacement of the object 50 in the X and Y directions may be determined.

Referring now to Figs 2a and 2b, there is shown an external cavity laser which includes a laser tube 100 which emits a beam 110 of laser light into an external cavity 112. Upon entering the cavity 112, the beam 110 is incident upon a birefringent prism 120 which splits the beam 110 into component beams 110A and 110B of differing polarisation states, which are to be directed into the polarisation maintaining optical fibres 12 and 14. Variations in temperature will affect the angles at which the two component beams 110A and 110B emerge from the birefringent prism 120. Because of the tight tolerances on the angles at which the beams must enter the fibres 12 and 14, the effects of temperature changes need to be compensated.

One method of achieving the required compensation would be to control the temperature of the laser cavity but

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the present invention deals with the problem in a novel way.

Temperature compensation is achieved in accordance with one aspect of the invention by the use of two additional beam steering prisms 130A and 130B positioned to direct the beams from the birefringent prism towards the ends of the fibres. The prisms 130A and 130B provide deviations in the beam paths due to temperature variations which are equal and opposite to those produced by the birefringent prism 120.

The fractions 110A' and 110B' of the beams 110A and 110B respectively which are transmitted through the steering prisms 130 emerge in a direction which, in this example, is substantially parallel to the beam 110 from the laser tube, and are subsequently directed into the polarisation maintaining optical fibres 12,14 respectively, via lenses (not shown) preferably with anti-reflective coatings.

The proximal ends of the fibres 12,14 are retained in connectors 142, which are in turn mounted to portions of a plate 144, the attitudes of which are independently adjustable within the housing in order to ensure that the axis of the fibre is correctly aligned with the axis of polarisation of the respective light beam. End faces of the fibres 12,14 are either cleaved, polished, and/or coated with an anti-reflective coating to prevent Fresnel reflected or scattered light from destabilising the frequency stability of the laser.

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In this example, the incident faces of the prisms 130A and 130B are slightly reflective such that a small fraction of each of the beams 110A and B is reflected therefrom onto an individual photodetector 132A and 132B respectively. The outputs of photodetectors 132A,132B are used to provide information enabling the laser tube to be frequency stabilised to the requisite degree of precision in a manner well-known per se, for example, by energising a heater coil (not shown) around the laser tube. Clearly the beam fractions required for stabilisation of the frequencies of the laser beams could be taken from other faces of the prisms.

Alternatively, stabilisation of the laser frequency could be performed using light emitted from the rear face of the laser tube.

Referring now to Figs 3 and 4 a sensing head 20 is shown connected at the opposite end of one of the fibre optic cables 12 by means of a connector barrel 200 mounted kinematically in the sensing head (see Figs 5a and 5b). Light emitted from the output end of the fibre 12 is collimated by means of a lens 201, and is subsequently incident upon a polarising cubic beamsplitter 202. The axis of polarisation of the light is aligned at 45° relative to the polarisation axis of the beamsplitter 202, so that half the light is transmitted through the beamsplitter 202 into a reference retroreflector 204, (which in this example is a corner cube retroreflector, but could be a plane mirror). The position of the reference retroreflector 204 is fixed relative to the beamsplitter 202 and therefore forms a reference arm. The remaining half of the light is reflected by the beamsplitter 202 (see Fig

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4) through a quarter waveplate 206, and steering prism 208 onto the plane mirror 60, connected to the object the position of which is being measured. The mirror 60 reflects the light substantially back along its path.

Having passed twice through quarter waveplate 206, the polarisation of the beam has now been rotated through 90° so that it is transmitted through the beamsplitter 202, and passes into a further retroreflector 212. The retroreflector 212 reflects the light once again through beamsplitter 202, quarter waveplate 206 and beam steering prism 208 onto the plane mirror 60, which once again reflects the beam back into the beamsplitter. Having passed once again through the quarter waveplate 206 on two occasions, the beam reflected at plane mirror 60 is now reflected at the beamsplitter 202, and combines with the reflected beam from retroreflector 204 to form an interference beam 220.

In accordance with another independent novel aspect of the invention, the interference beam 220 passes through a birefringent wedge prism 214, which refracts the beam reflected from the plane mirror 60 and the beam reflected from reference retroreflector 204 to different extents, as a result of their differing polarisations. Both of these beams then pass through a polaroid 216, the axis of which extends at 45° to the directions of polarisation of each of the beams forming the interference beam 220, thereby to mix their polarisation states and cause genuine interference. Because the beams are non-parallel, a spatial fringe pattern will result, and this is incident upon a detector array 218.

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The detector which may be substantially of the type disclosed in our prior published patent application US 5,302,820 produces a series of cyclically modulating phase-shifted electrical signals during motion of the plane mirror 60 away from and toward the beamsplitter 202. Such a detector includes a plurality of elongate photosensitive elements spaced commensurate with the spatial fringe pattern. In order to finely tune the spread of the fringe pattern to the spacing of the detector elements, the detector array may be mounted for angular movement relative to the fringe pattern, or the birefringent prism may be mounted for rotation relative to the detector.

Because the different frequency beams from the laser are distinct, the readings transmitted back from the interference signals derived from each beam may be converted to common metrological units, even though the fringe pitches are different.

In an alternative embodiment a ¼ waveplate could be included between the end of the fibre 12 and the beamsplitter 202, to generate substantially circularly polarised light incident on the beamsplitter 202.

The reference and measurement arms of the interferometer are preferably locally thermally balanced to ensure uniform changes in dimensions with a change in temperature, so that the fringe count is independent of the temperature of the sensing head.

Other forms of detector may be used. For example in a modification of the present embodiment, a remote detector unit (as described in our US Patent No.

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4,996,416) could be used. In an example of such a system the reference and measurement beams would be passed through a quarter waveplate, oriented at 45° to produce a linearly polarised output beam, the polarisation angle of which is dependent upon the phase difference between the measurement and reference arm beams. This interference beam is split into at least two further beams, and is then passed through polarising elements arranged at 45° with respect to each other, such that the light intensity of the subsequent output beams are in a quadrature relationship. These beams are then focussed separately into multimode fibres and are transmitted along the fibres into the laser head where photodetectors are located, for converting these sine and cosine optical signals into electrical signals, where they may be locally processed or transmitted to a machine tool controller, for example. In a further modification, the optical fibres may be taken directly to the machine tool controller, where the optical signals are transduced into electrical signals recognisable by the controller.

In still another modification to the embodiments described above, instead of having a remote laser and connecting it to the sensing head by means of fibre optic cables to provide the light source for the head, the laser may be mounted directly in the sensing head.

In order to ensure ease of alignment, in accordance with another independent novel aspect of the invention the steering prism 208 is mounted in a rotatable bracket 240 the attitude of which may be adjusted

relative to the housing, in a manner illustrated in Fig 6.

Referring also now to Fig 6, the beam steering prism 208 is fixedly retained within the bracket 240, typically by gluing. The bracket 240 is substantially circular, and has a pair of circumferentially extending flanges 250 creating a circumferentially extending slot 260, which is engaged by the jaws 270 provided by an aperture in the housing of the remote sensing head. A pair of bolts 274 project through the outer flange 250 and bear against the jaws 270 of the housing. Rotation of the bracket 240, and thus the prism 208 about an axis X, (Fig 6), causes the light beam to deflect along a substantially conical path. In the present example the bracket 240 is permitted to rotate through a limited angular range of virtue of mechanical stops (not shown), such that the pitch of the light beam about the X axis is varied. Rotation of the bracket is permitted by loosening of the bolts 274.

To enable relatively fine adjustment of the pitch from a relatively coarse rotation of the bracket 240, and thus prism 208, the prism 208 is aligned such that when at the mid-point of its permitted adjustment range its plane of symmetry extends substantially horizontal, i.e. parallel to the X axis.

Adjustment of the yaw i.e. rotational displacement of the beam about axis Z orthogonal to the X axis is performed by means of a corresponding bodily rotation of the remote sensing head. This is enabled by virtue of a generous clearance between the bolts 280 (see

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Fig 3) which secure the sensing head to the platform upon which it is to be used, and the housing.

To ensure accurate re-alignment of the fibre optic cable 12 in the sensing head 20, the connector barrel 200 is kinematically located in the head (Figs 5a and 5b). This is achieved, in this example, by providing orthogonal flat surfaces 300,302 on a fixed part of the head on which the cylindrical surface of the barrel seats. A ball 304 is urged by a spring or screw (not shown) into a conical recess in the opposite surface of the barrel thus preventing any translations or rotations of the barrel.

CLAIMS

1. Apparatus for producing and guiding a light beam comprising:

a laser for generating a laser beam, and a cavity external to the laser which receives, at an input end thereof, the beam from the laser, wherein two fibre optic cables are provided each of which has an end attached to an output face of the cavity, and an optical system is positioned in the cavity to receive the laser beam, said optical system including a birefringent prism which produces from the laser beam two beam parts which are directed into said ends of the fibre optic cables.

2. Apparatus according to claim 1 wherein the laser further comprises two further beam steering prisms for directing the two beams from the birefringent prism onto the ends of the fibre optic cables.

3. Apparatus according to claim 2 wherein the beam steering prisms are made from the same material as the birefringent prism whereby any deviations in the angles of the beams passing through the birefringent prism due to temperature variations are compensated by the beam steering prisms.

4. Apparatus according to claim 1 wherein the laser tube produces a beam which has two orthogonal polarisation states, each of the beams produced by the birefringent prism being polarised in one of the two states, and the fibre optic cables into which the beams are directed are made from polarisation maintaining fibres.

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5. Apparatus according to claim 2 wherein the laser is stabilised using beams taken from the two beam steering prisms.

6. Apparatus for producing and guiding a light beam comprising:

a light source for producing a light beam,

a sensing head for directing a portion of the light beam towards an object,

means for mounting the head on a base in a position relative to the object, wherein

the head includes a rotatable wedge prism through which the light beam is directed towards the object and rotation of which varies the direction of the beam in a first plane, and

the mounting means includes adjustment means for adjusting the orientation of the head to vary the direction of beam in a second plane orthogonal to the first plane.

7. Apparatus according to claim 6 wherein the sensing head includes an interferometer which generates said portion of the light beam and a reference beam and receives a beam reflected from the object, the interferometer producing from the reflected beam and the reference beam an interference beam, and a detector system which derives measurement data from the interference beam.

8. Apparatus according to claim 7 wherein the detector system includes:

a birefringent prism which receives the interference beam and produces therefrom two beams,

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a polaroid which receives the two beams and produces a spatial interference fringe pattern, and

a detector having spaced detecting elements which receive the spatial interference pattern.

9. Apparatus according to claim 8 wherein the birefringent prism and the detector are relatively angularly adjustable to enable the spacing of the fringes in the spatial interference fringe pattern to coincide with the spacing of the detecting elements of the detector.

10. Apparatus according to claim 6 wherein the light source is a laser mounted within the sensing head.

11. Apparatus according to claim 6 wherein the light source is a remote laser which is connected to the sensing head by at least one fibre optic link.

12. Apparatus according to claim 11 wherein the fibre optic link from the remote laser, terminates at the sensing head in a housing which is mounted kinematically within the sensing head.

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Fig.1.

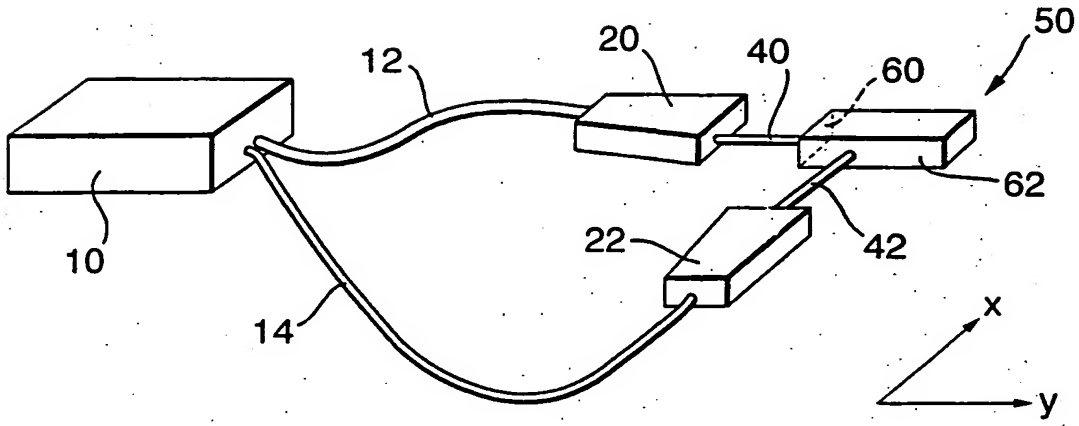
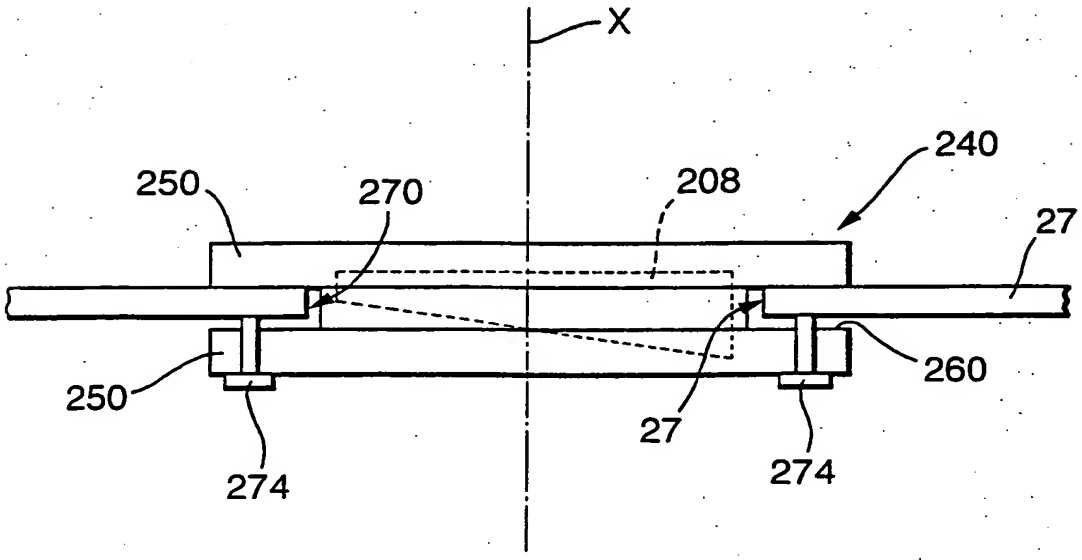
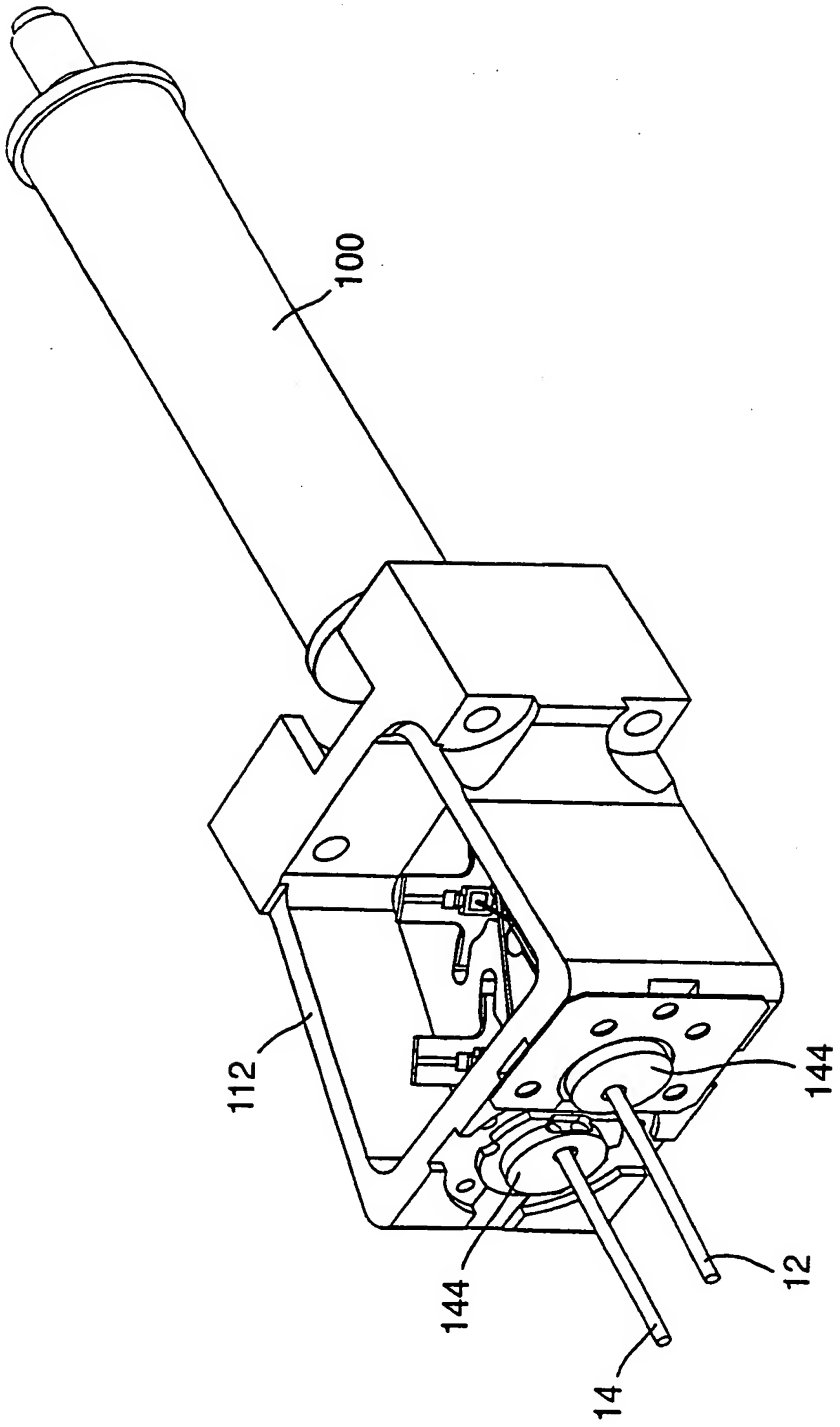


Fig.6.



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Fig.2a.



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Fig.2b.

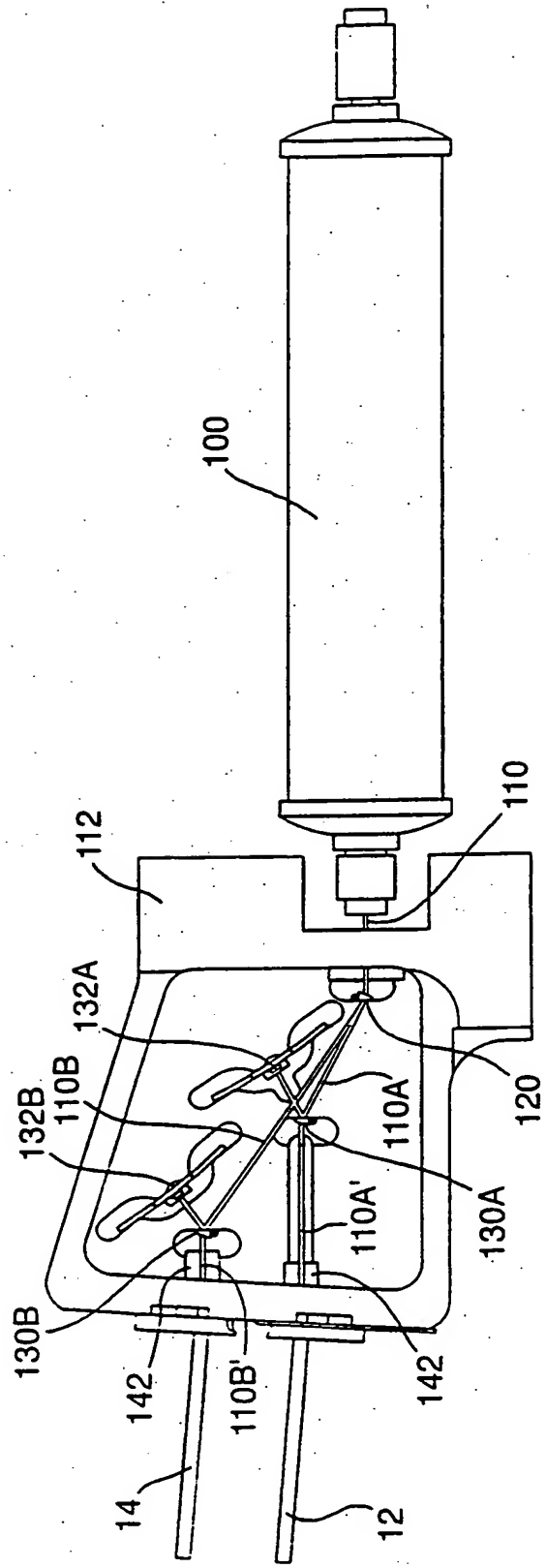

100
110
112
132A
110B
132B
110A
120
130A
110A'
130B
142
110B'
142
14
12

Fig.3.

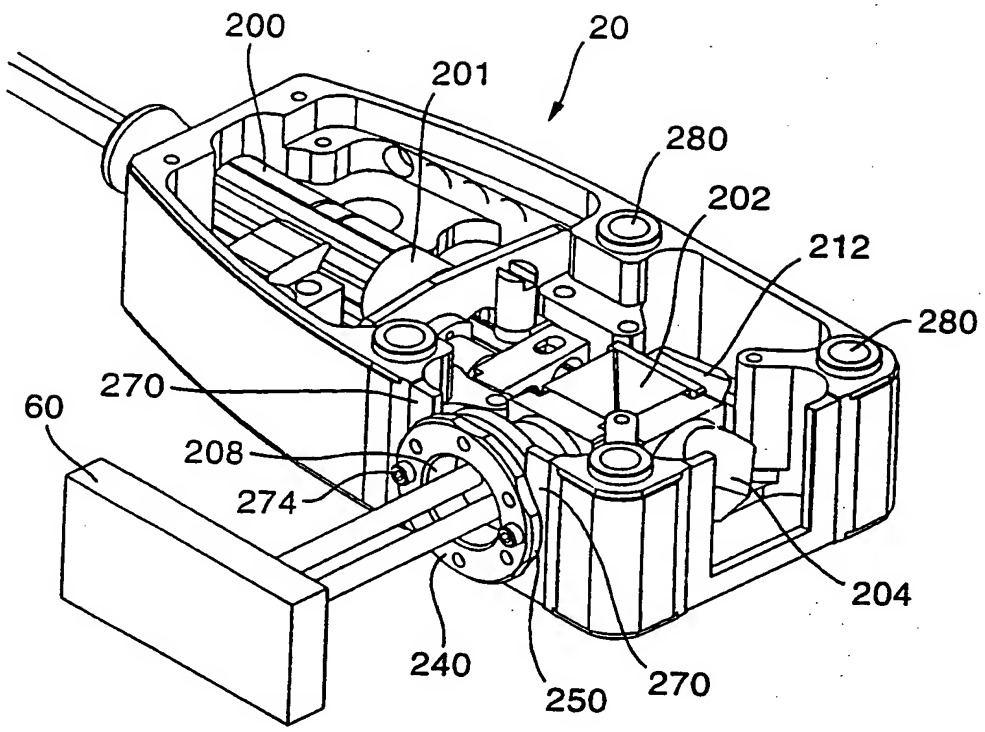
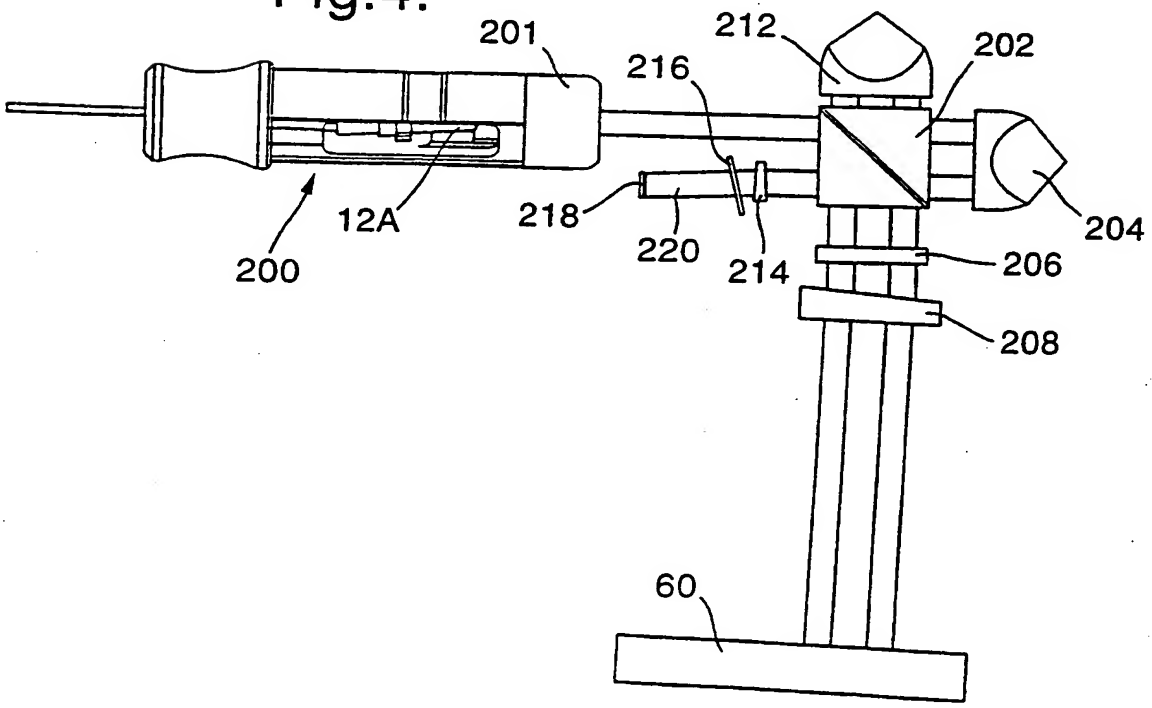


Fig.4.



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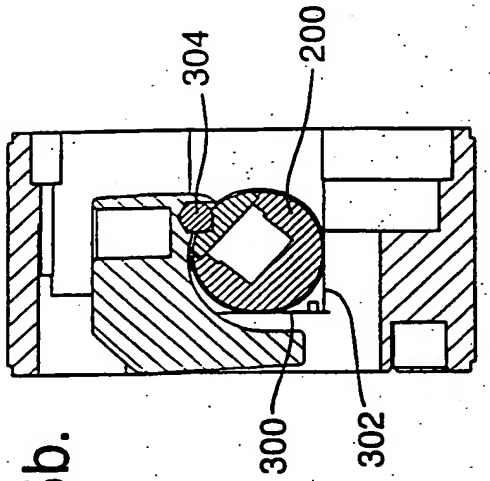


Fig.5b.

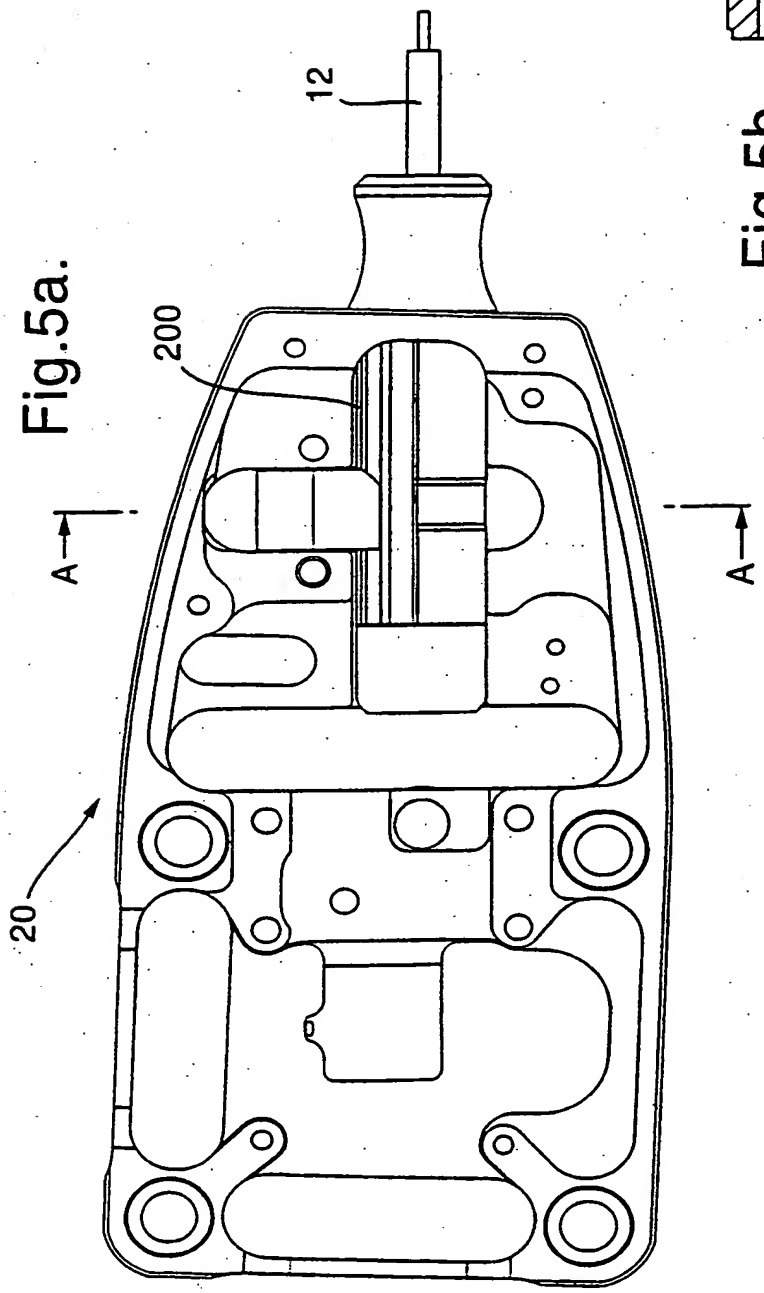


Fig.5a.

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(74) Agent: **WAITE, John**; Renishaw plc, Patent Department, New Mills, Wotton-under-Edge, Gloucestershire GL12 8JR (GB).

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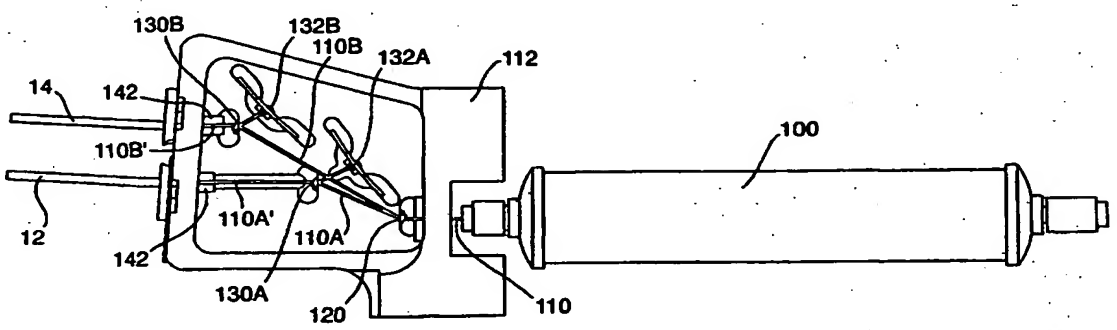
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INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
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According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 648 848 A (AIYER ARUN A) 15 July 1997 (1997-07-15) abstract; figure 2 column 2, line 7 - line 28 column 3, line 13 - line 29 column 3, line 46 - line 57 column 2, line 39 - line 52	1,4
A	---	6-12
A	US 4 221 460 A (HEPNER GEORGES ET AL) 9 September 1980 (1980-09-09) abstract; figures 2-4 column 3, line 23 -column 5, line 36	1-12
A	---	
	US 5 689 367 A (HUANG YONGLIN ET AL) 18 November 1997 (1997-11-18) abstract; figure 2	1-12

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 December 2000	15. 01. 01

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Jakober, F

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Intern[illegible]lication No
PCT/GB 00/01080

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 824 251 A (SLOTWINSKI ANTHONY R ET AL) 25 April 1989 (1989-04-25) abstract; figures 1,2 column 1, line 7 - line 14	1-12

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INSPEC(R) <WO 0057228A3 I >

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 00/01080

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

INSDOCID: <WO___0057228A3_I_>

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-5

   Temperature compensated beam splitter

2. Claims: 6-12

   Apparatus for sensing movements of an object

INTERNATIONAL SEARCH REPORT

Information on patent family members

Interr. Application No
PCT/GB 00/01080

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5648848 A	15-07-1997	DE 19601692 A	22-08-1996
		GB 2298054 A,B	21-08-1996
		JP 8240792 A	17-09-1996
US 4221460 A	09-09-1980	FR 2403567 A	13-04-1979
		DE 2840254 A	29-03-1979
		GB 2005043 A,B	11-04-1979
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US 5689367 A	18-11-1997	US 6018418 A	25-01-2000
		US 5923470 A	13-07-1999
US 4824251 A	25-04-1989	NONE	

ISDOCID: <WO___0057228A3_I_>